Total Dose Effects and Hardness Assurance for Optocouplers*

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Introduction

The operation and efficiency of optocouplers depend on a number of different factors, and the way that these factors arc degraded by radiation most be properly understood in order to apply these devices in space systems. Previous work on optocouplers has shown that light emitting diode (LED) degradation is often the dominant factor in their response, and that little degradation occurs until levels above 100 krad(Si) are reached.[1] However, optocouplers can be fabricated in a number of different ways, and the details of the manufacturing process can have a large influence on their radiation performance. in particular, the type of LED and detector used to fabricate the optocoupler has a substantial impact on coupler radiation response.[1-4] Recent work at JPL, has shown that some types of optocouplers arc extremely sensitive to ionizing radiation, exhibiting significant degradation at levels of approximately 10 krad(Si). This paper investigates the mechanisms for this behavior, as well as hardness assurance methods which arc important for this class of devices.

Device Description

Optocouplers arc made with a variety of very different physical configurations. In the case of devices examined in this study two different configurations are used. One approach uses a sandwiched constriction method, with the LED mounted directly over the photodiode. The second approach mounts an LED and phototransistor side by side, using an optical coupling medium to partially couple light between the LED and phototransistor. Figure 1 compares these two construction methods.

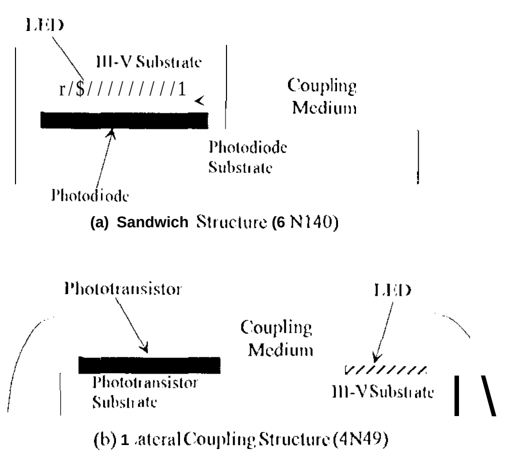

Figure 1. Physical Arrangement of Two Common Types of Optocouplers.

The 4N49 is a hybrid device consisting of an amphoterically Si doped GaAs LED, and a silicon phototransistor which is designed to collect light from the top surface. Both components arc mounted horizontally, and hence there is little direct coupling of light from the LED to the phototransistor. A silicone compound is used to increase the optical coupling efficiency, guiding some of the light 10 the top surface of the transistor because of total internal reflection. The silicone compound is simply a "blob" placed over the two die, with no explicit control over thickness or uniformity. '1'bus, the coupling efficiency depends on a number of physical factors as well as on the optoelectronic properties of the semiconductor devices. This will likely cause moth larger variations in the radiation response of these devices, and makes it far more difficult to estimate the effects of statistical variations in component properties on the radiation response. As one would expect from this construction method, the initial CTR values of devices varied widely. A histogram of the spread in CTR of 145 JAN-TX-4N49 devices is shown in Figure 2. Note that many of the devices had CTRs near the minimum value of 2. The CTR of a small test sample used for radiation testing varied from 202 to 347°/0. The minimum requirement is 200%, and one unit was within 1% of failing this requirement

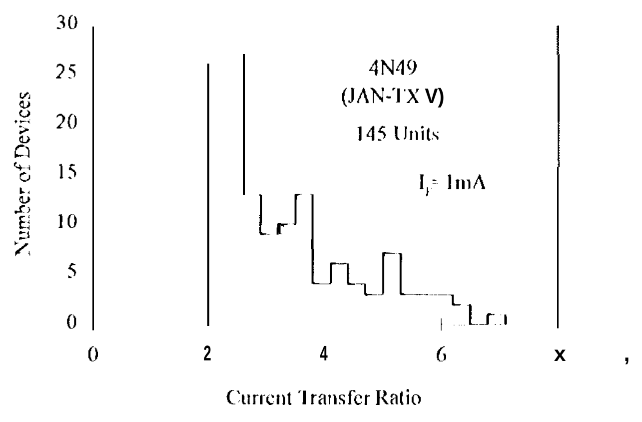

Figure 2. Spread in CTR for a Single Lot of 4N49 Optocouplers (Not Irradiated).

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A device with low initial CTR was opened after it was irradiated to 100 krad(Si) to determine whether any physical features contributed to the lower CTR. Examining this device with a microscope showed that there were several large bubbles in the silicone coupling compound (a babble has a lower refractive index and will prevent light from entering the region blocked by the bubble). The largest bubble was near the direct light path from the LED, and would clearly alter tbc amount of light coupled to tbc phototransistor. This shows that the physical characteristics of the assembly can be important in determining the coupling, efficiency, and strongly suggests that unit-to-unit variations in performance will be much larger for these types of optocouplers than for conventional electronic devices where electrical properties arc generally unaffected by assembly details.

The second type of optocoupler, 6N 140, is fabricated with the sandwich construction shows in Figure la. This approach not only provides improved coupling efficiency, bat also reduces unit to unit variations in CTR. The 6N140 uses a Darlington circuit coupled to a photodiode with a separate bias connection for the photodiode. This increases CTR compared to the single phototransistor of the 6N140.

Experimental Approach

Radiation tests were done with the LED grounded, and the collector of the detector at 30V (4N49) or 15V (6N 140). A cobalt-60 source was used for irradiation at dose rate of 50 rad(Si)/s. In addition to performing a variety of standard optocoupler tests to determine how various components in these optocouplers degrade, physical assemblies were setup using either an external LED to excite tbc phototransistor from outside the test coupler; or an external photodetector to measure light emitted from the LED member of the test coupler. These measurements were only possible with the 4N49 devices which uses lateral coupling. The silicone coupling compound was removed from some of tbc optocouplers in order to eliminate the coupling medium. The effect of the coupling compound could then be determined by comparing measurements of the two groups of devices.

Total Dose Test Results

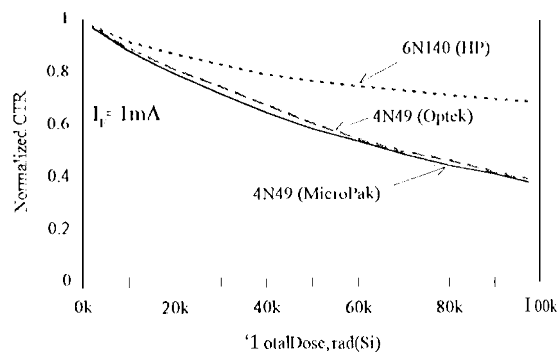

Figure 3. Comparision of CTR Degradation

The parameter that was most affected by radiation was current transfer ratio. The specification limit of the 4N49 is 200% with a drive current of 1mA. Figure 3 shows the test results for CTR of the two 4N49 manufacturers along with the 6N 140, as a function of total dose under room temperature coalitions. At 100 krad(Si), the CTR of both Optek and Micropak devices had decreased to less than 40% of the initial value. Less degradation occurred for the 6N 140. This is expected because of the improved coupling efficiency of the structure, and the use of a Darlington-connected compound photodiode.

Test results with an external LED were used to compare tbc CTR degradation of 4N49 devices with and without the silicone coupling compound. Figure 4 shows that the degradation was essentially the same, regardless of whether the coupling compound was present. This shows that the transmission of the

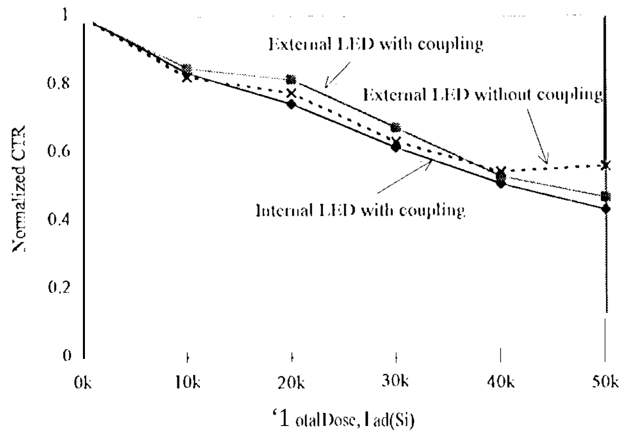

Figure 4. Comparision of Internal and External LEDs for MicroPak Optocoupler.

silicone is not a factor in degradation of these optocouplers. This is not surprising because of the very short optical pathlength in the coupling medium. Furthermore, degradation with the external LED was so close to that of degradation of normal (lidded) devices with the internal LED that it appears that the degradation is dominated by the photoresponse of the transistor.

Gain of the 4N49 phototransistor was also measured as a function of total close. Transistor gain, nominally 600, decreased by about 15% at 100 krad(Si). However, the photoresponse of the transistor depends on collection of light by diffusion in the extended area of the collector as well as gain, and degrades mote severely. Here, it is worth noting that tbc amphoterically Si doped GaAs LED has an emission peak at longer wavelengths closer to the Si absorption edge. "1'has, the light is mote deeply penetrating. The response of the delidded devices with external LED provides direct evidence that the reason for degradation is the overall transistor photoresponse.

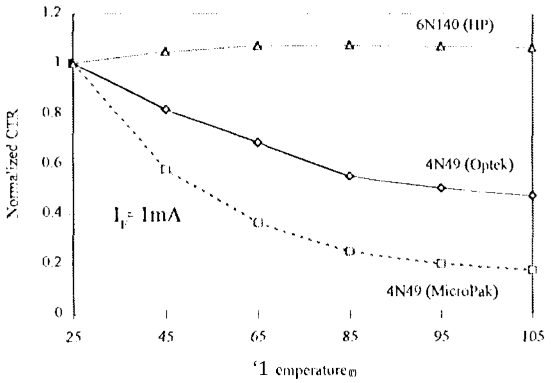

Figure 5. Temperature Dependence of CTR.

Hardness Assurance Considerations

The output of LEDs decreases as temperature increases. This causes substantial decrease in optocoupler CTR at higher temperatures, which is a concern for the Cassini project. Measurements of temperature sensitivity were made on unirradiated devices as well as devices that were irradiated to 100 krad(Si). Although CTR was reduced by radiation, the temperature sensitivity of CTR remained the same.

Figure 5 compares the temperature sensitivity of the three different optocouplers. Note that the CTR of the 4N49 from MicroPak decreased by more than a factor of two compared to devices from Optek, even though these were both JAN-TX devices with the same electrical specifications. This difference was critically important in selecting devices for radiation applications. Even though radiation degradation of optocouplers from the two vendors was about the same at room temperature, the marked difference in temperature sensitivity resulted in a much lower design limit for the two manufacturers. An even greater difference was observed, as shown in Figure 5, when the HP optocoupler is compared with the other two types. Note that the CTR of the HP devices actually inceases over part of the temperature range. This difference can be attributed to the different detector structure and possibly also a different LED type.

The output saturation voltage of 4N49 showed some degradation. Although this is also affected by the very small sample size, there is less risk because this parameter is less affected by parametric variations, and is expected to remain low as long as the CTR is adequate to support the saturation characteristics. Thus, designing with adequate CTR will indirectly ensure that the saturation voltage remains well behaved. Note, however that the input drive current must be significantly greater than the minimum CTR required for a specified output current in order to drive the transistor into the saturation region. This means that the CTR used for design must be well above the minimum CTR after irradiation. The saturation measurements were made with a drive current of 2 mA and a forced gain of one; CTR measurements were made with an optical drive current of 1 mA, as per the specification. Thus, the saturation characteristics assume approximately a factor two "excess" CTR to provide overdrive to the phototransistor in saturation.

All of the devices that were tested had initial leakage currents that were well below the specification maximum, and leakage current increased only slightly after irradiation. However, these results are not adequate to characterize leakage current performance after irradiation because devices with initial leakage currents that are higher may exhibit very large increases after irradiation. This has been observed for some types of discrete transistors. Thus, no worst-case value can be arrived at for these devices from the limited data available. It is recommended that the screening data provided by the manufacturer be examined to see if any devices in the population have initial values above 10 nA. Devices with initial leakage currents in the 10-100 nA range may increase by several orders of magnitude at 100 krad(Si). In fact, examination of screening data on the production lot showed that about 10 % of the devices had unusually large leakage currents. Several were about 10 nA, and one device had a leakage current of 28 nA. Although still below the specification limit, these devices may be affected more strongly by radiation than the devices in the radiation test sample with low initial values of leakage current. The large statistical range of leakage current in the production lot suggests that radiation-induced changes in leakage current may also be an important factor for these optocouplers. Additional tests will be done for the final paper to examine leakage current in more detail.

Summary

The results in this paper shows that radiation degradation of optocouplers is affected by many factors, including details of the mechanical assembly. These are hybrid devices, and the net response depends on the interplay of many different variables, leading to larger variations in electrical parameters than is normally encountered with simpler structures. Mechanical assembly details are also important. There are clear advantages to the sandwich structure because it provides more efficient coupling than the lateral structures, and may provide better uniformity.

Measurements of delidded devices with an external LED showed that degradation was dominated by the decrease in transistor photoresponse. Although radiation degradation is not directly affected by temperature, the strong decrease in CTR at elevated temperature must be accounted for when evaluating these devices for space applications. Large differences in temperature sensitivity were observed for different manufacturers. Another important factor that must be considered for CTR degradation is aging. LED and photo response of optocouplers would degrade as a function of time. The aging analysis will be studied for the final paper.

Optocouplers are very sensitive to ionizing radiation, and careful thought is required in order to develop appropriate hardness assurance methods for them. Examining electrical parameters of a large lot showed that CTR and leakage current varied widely, and that typical data from a small sample would overestimate the effective radiation hardness of these devices because of the importance of variations in factors that affect device operation. Although sample testing is still useful, the results of this study suggest that it will also be necessary to monitor electrical properties of the production lot in order to adquately bound the radiation response.

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